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Influence of fibers geometry on the intake height PP yarns

Pavol Lizák[a],*, Jela Legerská[a]

[a]Alexander Dubček University of Trenčín, Faculty of Industrial Technologie, I. Krasku 491/30, 020 01 Púchov, Slovakia

Abstract

Fibrous materials represent an important product in the application of fibres destined for clothing production, indoor textiles production and technical textiles production. Different kinds of clothing are used in direct or indirect contact with human skin. These types of textiles require appropriate utility properties, mainly suitable heat and moisture transport - physiological properties. This work examines the effect of the geometry of PP fibres on the structure and utility properties of textiles – thermoclothing. The fibers geometry highly influences the heat and mass transfer through textile clothing. Four polypropylene fibers of different cross sectional shapes namely four channel profile, round hollow, round and hollow triangle were used in this work. A relationship between the called shape factors for the different fibers was established. The intake heights were analyzed. It was found that the size of the surface area has an impact on process of processing fibres, determines the penetration of gases or liquids, sorption and diffusion in the fibres. The cross sectional shape of fibers has also influences the heat and mass transfer through textile clothing.

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Keywords: PP fibers; porosity; cross-sections; packing density

1. Introduction

The fibre formations are in its structure and its behaviour fully subordinated to the general laws of natural, which are researched by the natural sciences. Currently modern science is interested in the study of the structure and behaviour of some special man-made materials. The packing density is characteristics expressing mutual arrangements of fibers in yarns. It is one of basic characteristics of structure, which is necessary for computation of inter-fiber contacts density, yarns porosity and pores size, yarns diameter, yarns compressibility, etc. [1]. Packing

* Corresponding author. Tel.: +421 905442287.
E-*mail address:* pavol.lizak@fpt.tnuni.sk

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density is suitable for internal structure comparison of yarn produced from different raw material or by different technologies. Set of yarn created from modified polypropylene fibers were investigated in this work. Cross-sections has been used for yarn packing density and porosity evaluation.

2. Fibers properties

Staple fibers are the fundamental units of yarn. So, the structural theory of yarn must include the required parameters of fibers and their relationships. One of most frequently used fiber parameters is the fiber fineness t. From geometrical standpoint, the fiber fineness is characterized by the ratio V/l, but the standard fineness is moreover influenced by fiber volume density ρ. Therefore, it is not correct to compare the fineness of fibers having different densities by the standard fineness; it is better to use the ratio t/ρ. Fineness t and density ρ define the cross-sectional area $s = t/\rho$. Cross-sectional area for circular fibers $s = \pi d^2/4$ enables to evaluate the equivalent fiber diameter d. For circular fibers, the derivation is trivial. For non-circular fibers, the same equation represents the diameter d of a circular having the same fiber cross-sectional area:

$$t = s\rho \tag{1}$$

$$d = \sqrt{\frac{4s}{\pi}} = \sqrt{\frac{4t}{\pi\rho}} \tag{2}$$

Fiber cross-section profile is described by shape factor. The shape factor is dependence on fiber cross-section dimensions [2]:

$$q = \left(\frac{p}{\pi d}\right) - 1 \tag{3}$$

where p is fiber perimeter and πd is effective perimeter of a circle of the same area s. For circular fiber cross-section it is valid that $p/(\pi d) = 1$, elsewhere $p/(\pi d) > 1$. The perimeter of a non-circular fibre is always higher than the perimeter of a circular having the same cross-sectional area. If we know the (typical) shape factor of our fibre in advance, we can calculate its perimeter from the following equation [2]:

$$p = \pi d(1 + q) \tag{4}$$

A lot of important properties of textiles (especially transport of moisture) depend on the total area of fibrous surface. Therefore, it is very useful to know the surface area per unit mass of fibrous material. (Note: We can neglect the topmost and bottommost cross sectional areas of fibers, because as fiber is very long, these two areas are specificly very small – e.g. 0.025%.) Specific fiber surface area a [3] is ratio of fiber surface area to fiber mass:

$$a = \frac{A}{m} = \frac{4(1+q)}{\rho d} = 2\sqrt{\pi}\,\frac{q+1}{\sqrt{\rho t}} \tag{5}$$

Values of specific fiber surface are about 10^2 m^2.kg^{-1} (for cotton is $\rho = 1520$ kg.m^{-3}, $q = 0.28$. The specific surface $a = 300.5$ m^2.kg^{-1}). In contrast values from adsorption isotherms are higher (for bleached cotton 6000–8000 m^2.kg^{-1}), due to surface microstructure, fiber micro-flaws, etc.

3. Experimental

The typical fibers with four channel profile (type 1), round hollow (type 2), round (type 3) and hollow triangle (type 4) polypropylene fibers were used (Fig. 1). From parallel fiber bundles fiber cross-sections of thickness about 15 μm were prepared. For preparation of cross-section the soft method (i.e. fiber pretreated by glue are sealed by mixture of beeswax and paraffin) were used. Fiber cross-section areas were measured by means of software for image analysis NIS Element.

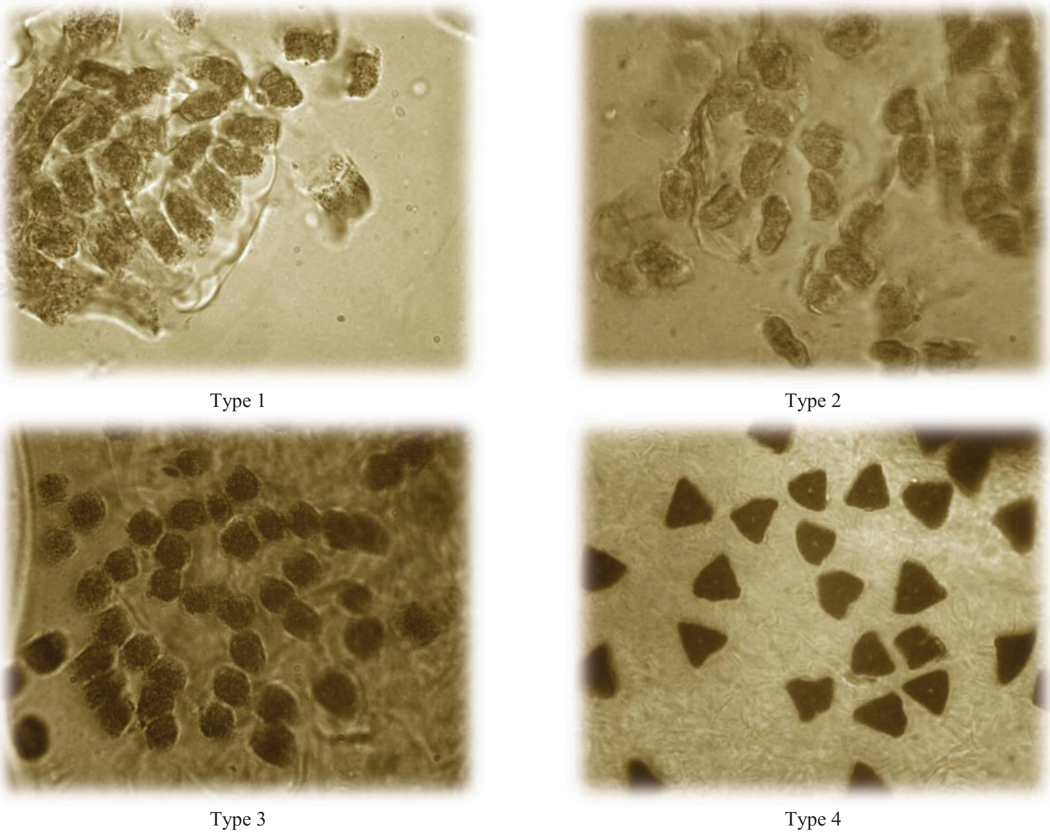

Fig. 1. Typical PP fibers with different cross-sections area.

Measured PP fiber cross-section area *s* and computed (with volume density $\rho = 980$ kg.m^{-3}) fiber fineness *t* – see eq. (1), effective diameter *d* – see eq. (2), shape factor *q* – see eq. (3) and specific surface area *a* – see eq. (5) are given in the Table 1.

Table 1. Fiber properties.

Type PP	Fineness *t* (tex)	Cross-sectional area *s* (μm^2)	Diameter *d* (μm)	Shape factor *q* (-)	Specific surface area *a* (m^2.kg^{-1})
1 – four channel profile	0.130	132.890	13.008	0.412	443.06
2 – round hollow	0.130	132.890	13.008	0.000	313.78
3 – round	0.100	102.041	11.398	0.000	358.09
4 – hollow triangle	0.175	178.571	15.079	0.286	348.10

The values of yarn fineness, diameter, fiber number in yarn cross-section, coefficient of fiber number and packing density were evaluated. The standard method has been used for measuring of yarn fineness.

The yarns cross-sections have been prepared by the same way as fibrous bundles. For treatment of yarn cross-sections images the direct method was used [5]. Image analysis of yarn cross-sections has been used for yarn packing density and porosity evaluation. The analysis is based on the functions of the software NIS Element (Laboratory Imaging). Results are given in the Table 2, 3 and Fig. 3.

Table 2. Yarn properties.

Type PP	Fineness T (tex)	Effective diameter D (mm)	Fiber number in cross-section n (-)	Coefficient of fiber number k_n (-)	Mean packing density μ (-)
1 – four channel profile	11.200	0.125	86	0.95	0.936
2 – round hollow	11.200	0.127	86	0.95	0.902
3 – round	10.000	0.123	100	0.95	0.865
4 – hollow triangle	11.200	0.142	64	0.95	0.720

For investigation of transport properties of textiles it is necessary to study connection of porosity with processes of capillary action and airflow or flow of liquids, etc.

To investigate relation of pore model with liquid transport in capillary system the liquid intake height was measured. Results are given in the Table 3. Yarn samples with pretension 15 mN.tex^{-1} were hung and immersed to liquid. As intake liquid the mixture 90% water and 10% isopropanol has been selected. This liquid has lower surface tension then water and it intake height is higher. The intake height can be expressed by the simple linear equation [4]:

$$IH = a.T.k_{IH} = 2\sqrt{\pi}(1-q)\frac{T}{\sqrt{\rho t}} \tag{6}$$

where a is specific surface area, T is yarn fineness and k_{IH} is constant (it depends on wetting energy). The experimental values and regression line expressed by eq. (6) are shown in Fig 2. For this case it was founded relation IH (mm) = 0.0078 a (m^2.kg^{-1}) T (tex).

Table 3. Yarn porosity.

Type PP	Porosity P (-)	Effective pore diameter d_p (mm)	d_p/d (mm)	L_p/L (-)	Intake height IH (mm)
1 – four channel profile	0.06	0.015	0.171	0.72	38.706
2 – round hollow	0.1	0.02	0.171	0.41	27.412
3 – round	0.14	0.019	0.161	0.44	27.931
4 - hollow triangle	0.28	0.016	0.171	0.58	30.411

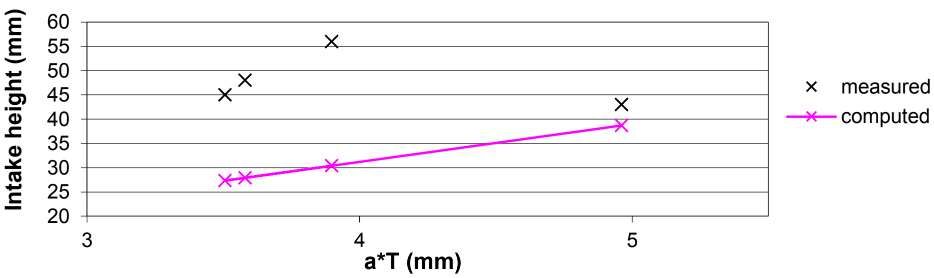

Fig. 2. Intake height.

4. Discussion

The coarser fibers have more complicated cross section (i.e. yarns type 4). Fibers of yarn type 2 have the smallest specific surface. The fiber specific surface of yarn type 1 is the highest.

Fineness of yarns type 1, 2 and 4 are 11.2 tex and the last fineness is 10tex. Twists are statistically non-significant. Fiber number in yarn cross-section is function of yarn fineness, fiber fineness and coefficient of fiber number ($k_n = n/(T/t)$). For example yarns type 1 and 2 have the same yarn fineness and also fiber fineness what leads to same fiber number in cross-section. Lower fiber fineness of yarn type 3 leads to higher fiber number in cross-section. These differences are quantified by coefficient k_n. For standard ring spun yarns are values of coefficient k_n is 0.95. It is valid for yarn type 1, 2, 3, 4. For some cases is coefficient k_n higher than one, i.e. measured values of fiber fineness are higher than real values. The reason is statistical variability of measured properties and inaccuracies in cross section creation.

Mean yarn porosity expressed as complement to mean packing density has opposite trend see table 3. The highest equivalent yarn diameter of pores results for yarn type 4 (the coarse fibers). The smallest equivalent pore diameter is for yarn type 3 (fine fibers and low shape factor). Ratio of equivalent pore diameter to equivalent fiber diameter d_p/d indicates that in yarn type 3 have narrow and long pores. Probably, the fiber fineness plays a crucial role in pores formation.

The highest intake height results for yarn type 1 and 4 with the narrow and long pores and the lowest intake height is for yarn type 2 with wide and short pores.

6. Conclusion

In this work the geometrical characteristics and porosity of yarn are described. Porosity defined as effective pores diameter is better for expression of air gaps size. Yarn porosity has often only minor influence on transport properties of textiles. On the other hand, it can be necessary to investigate porosity for specific purposes as wicking, wetting etc.

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